

Abstract for Symposium on Formation Flying Missions and Technologies

Title: Relative Navigation of Formation-Flying Satellites

Authors:

Anne Long (Anne.Long@csc.com), David Kelbel (David.Kelbel@csc.com), Taesul Lee (Taesul.Lee@csc.com), and Dominic Leung (Dominic/Leung@csc.com)
FAX: 301.794.7208
Computer Sciences Corporation
7700 Hubble Drive
Lanham-Seabrook, Maryland USA 20706

Russell Carpenter (Russell.Carpenter@gsfc.nasa.gov) and Cheryl Gramling (Cheryl.Gramling@gsfc.nasa.gov)
FAX: 301.286.0369
Code 572 NASA Goddard Space Flight Center
Greenbelt, Maryland USA 20771

Formation-flying techniques and satellite autonomy will revolutionize space and Earth science missions and enable many small, inexpensive satellites to fly in formation and gather concurrent science data. The Guidance, Navigation, and Control Center (GNCC) at Goddard Space Flight Center (GSFC) has successfully developed high-accuracy autonomous satellite navigation systems using the National Aeronautics and Space Administration's (NASA's) space and ground communications systems and the Global Positioning System (GPS). In addition, an autonomous navigation system that uses celestial object sensor measurements is currently under development and has been successfully tested using real Sun and Earth horizon measurements. Recently, the GNCC has leveraged this experience to develop advanced spacecraft systems that provide autonomous navigation and control of formation flyers in near-Earth, high-Earth, and libration-point orbits.

To support this effort, the GNCC is assessing the relative navigation accuracy achievable for proposed formations using GPS, intersatellite crosslink, ground-to-satellite Doppler, and celestial object sensor measurements. Figure 1 illustrates the relative navigation approaches under investigation. This paper evaluates the performance of these relative navigation approaches for three proposed missions with two or more vehicles maintaining relatively-tight formations.

High-fidelity simulations were performed to quantify the absolute and relative navigation accuracy as a function of navigation algorithm and measurement type. Realistically-simulated measurements were processed using the extended Kalman filter implemented in the GPS Enhanced Onboard Navigation System (GEONS) flight software developed by GSFC GNCC. Solutions obtained by simultaneously estimating all satellites in the formation were compared with the results obtained using a simpler approach based on differencing independently-estimated state vectors.

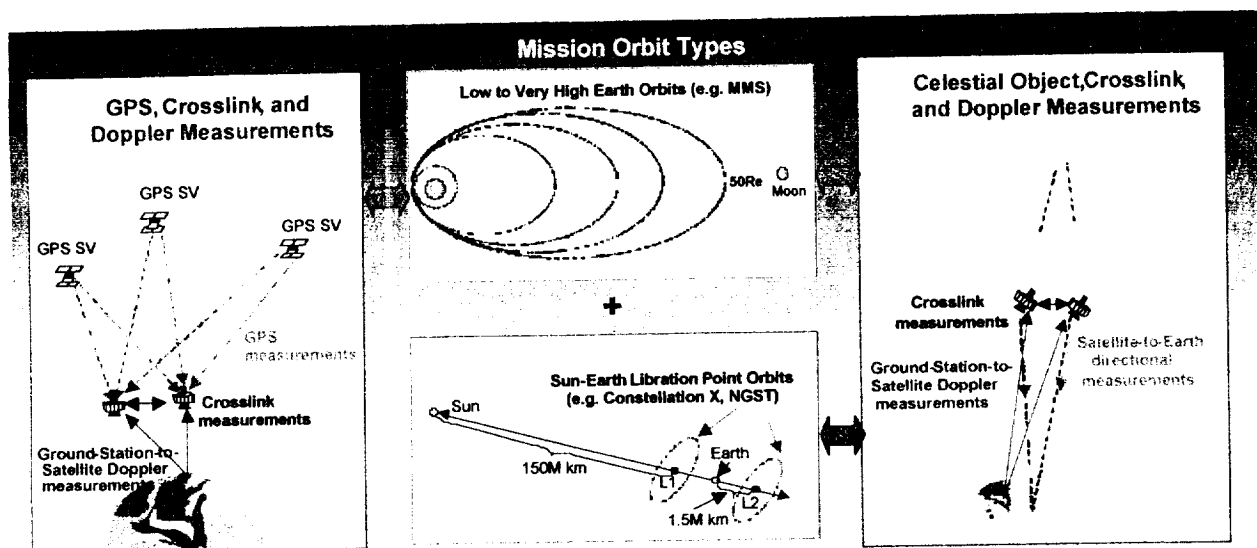


Figure 1. Candidate Relative Navigation Approaches

We evaluated the navigation performance for a formation consisting of four satellites maintained in medium-altitude Earth orbits (MEOs) of approximately 500x7000 kilometer altitudes at an inclination of 80 degrees. The orbital period is about 3 hours. For this formation, the real-time relative position knowledge requirement is about 100 meters for the initial 30-kilometer separation and reduces to 5 meters for the 500-meter separation formation later in the mission. Figure 2 shows the results from Monte-Carlo simulations processing civilian GPS pseudorange measurements, which produced an absolute position accuracy of 3.5 meters RMS and relative position accuracy of 0.4 meters RMS. Improvements to be achieved through the estimation of GPS space vehicle biases, differencing of GPS measurements, and addition of intersatellite range measurements were evaluated and found to provide comparable performance to those obtained by differencing independently-estimated state vectors.

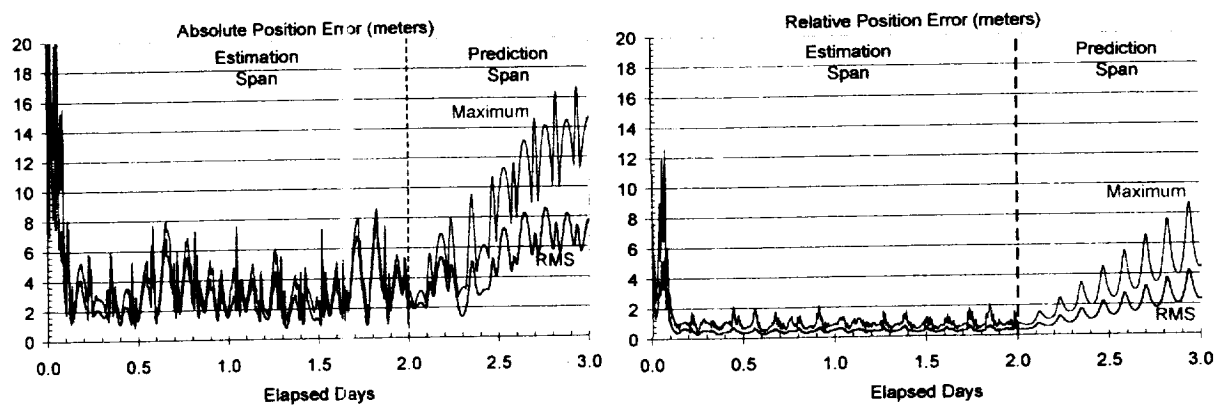


Figure 2. Absolute and Relative Position Accuracy for MEO Formation Using GPS

The second formation evaluated consists of five satellites in eccentric high-Earth orbits (HEOs) of approximately 1.2 x 12 Earth radii at an inclination of 10 degrees, similar to the first phase of the Magnetospheric Multiscale (MMS) mission. The orbital period is approximately 1 day. The inter-satellite separation varies from 10 kilometers to 0.1 Earth-radii. The absolute position knowledge requirement is 100 kilometers and the intersatellite position knowledge requirement is 1 percent of the actual separation. Figure 3 shows the absolute (60 meters RMS) and relative

(25 meters RMS) Monte Carlo position error statistics for this formation, processing civilian GPS pseudorange and round-trip intersatellite range measurements. This simulation used a GPS receiver with an acquisition and tracking threshold reduced to 30-dB-Hertz to significantly increase the number of GPS satellites that can be acquired in this orbit, which spends more than half of its period above the GPS constellation. For this HEO formation, the addition of intersatellite round-trip range measurements was found to yield a reduction of more than 50 percent in the relative navigation error.

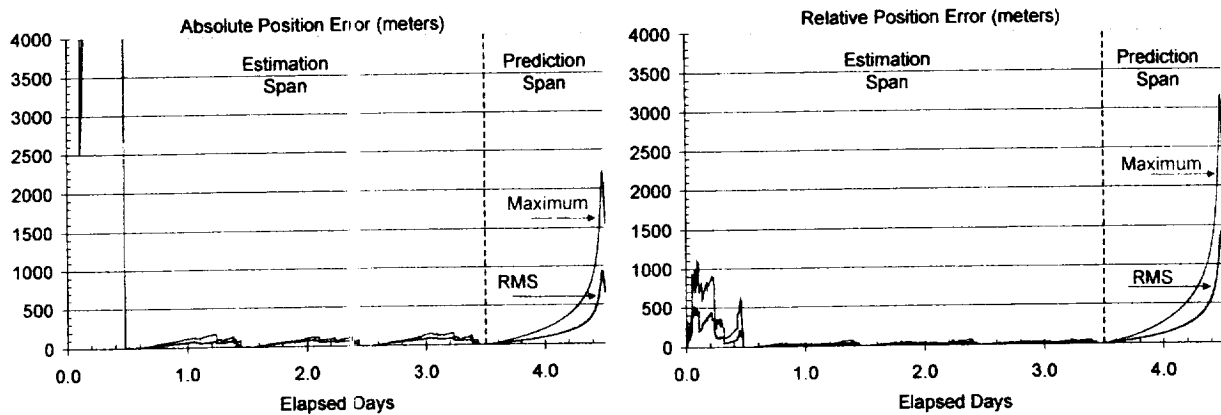


Figure 3. Absolute and Relative Position Accuracy for HEO Using GPS and Round-Trip Intersatellite Measurements

We are currently evaluating navigation performance for the Constellation-X Observatory, which consists of several X-ray telescopes on spacecraft orbiting in close proximity and work in unison to generate the observing power of one giant telescope. The current design calls for four spacecraft placed in a loose formation orbiting about the Sun-Earth L2 libration point. This study focuses on quantifying the autonomous absolute and relative navigation accuracies achievable for the Constellation-X Observatory using celestial object (e.g. Earth, Moon, Sun) sensor measurements alone or in combination with intersatellite range measurements and ground-to-spacecraft Doppler measurements.

The paper will provide a detailed discussion of the relative navigation accuracy results for each of these formations as a function of the navigation algorithm and tracking measurement characteristics.

International Symposium **FORMATION FLYING** Missions & technologies



Version Française



esa

JPL



Committees - Objectives - Background - Call for papers - Information

NASDA

cnes



29, 30 and 31 October 2002
Centre National d'Etudes Spatiales
Toulouse Space Centre - France



Calendar

| | |
|---------------------------|--------------------------------|
| Submission of abstracts | February 15, 2002 |
| Program Committee meeting | March 7, 2002 - CNES HQ, Paris |
| Notification to authors | March 29, 2002 |
| 2nd announcement | April 15, 2002 |
| Final paper submission | September 16, 2002 |

Date and venue

The Conference will be held on
October 29, 30 and 31, 2002 at the **Centre National
d'Etudes Spatiales**

Toulouse Space Centre, 18, av. Edouard Belin.

<http://www.cnes.fr>

Further information on Toulouse is available on the following
web site:

<http://www.mairie-toulouse.fr>

Registration fee

- **Registration Fee: 250 € VAT Incl.**

Registration fee covers access to the meeting rooms, the
coffee breaks, the lunches and the proceedings that will
be distributed on the first day of the Conference.

Further information

For further information, please contact:

Agnès Letraublon - CNES

Délégation à la Communication et à l'Education

18, avenue Edouard Belin

31401 Toulouse Cedex 4 - France

Phone: +33 (0) 5 61 27 36 26 - Fax: +33 (0) 5 61 28 29 39

E-mail: agnes.letraublon@cnes.fr

or

Karin Moens - CTA

21, avenue de Fondéyre - 31200 Toulouse - France

Phone: +33 (0) 5 34 40 57 60 - Fax: +33 (0) 5 34 40 66 15

E-mail: karin.moens@cta-congres.com

[< top](#)